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Centre number

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Candidate number

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Forename(s)

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I declare this is my own work.

A-level PHYSICS

Paper 3

Section B Medical physics

Friday 5 June 2020

Afternoon

Time allowed: The total time for both sections of this paper is 2 hours. You are advised to spend approximately 50 minutes on this section.

Materials

For this paper you must have:

- a pencil and a ruler
- a scientific calculator
- a Data and Formulae Booklet.

Instructions

- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- If you need extra space for your answer(s), use the lined pages at the end of this book. Write the question number against your answer(s).
- Do **all** rough work in this book. Cross through any work you do not want to be marked.
- Show **all** your working.

Information

- The marks for questions are shown in brackets.
- The maximum mark for this paper is 35.
- You are expected to use a scientific calculator where appropriate.
- A Data and Formulae Booklet is provided as a loose insert.

For Examiner's Use

Question	Mark
1	
2	
3	
4	
TOTAL	



J U N 2 0 7 4 0 8 3 B B 0 1

Section B

Answer **all** questions in this section.

0 1 . 1

State and explain **two** differences between the perceived image of a brightly coloured object in bright light and the perceived image of the same object when viewed in very dark conditions.

In your answer you should refer to the visual receptors in the eye.

[5 marks]

Difference 1 *Colour: in bright light the object is seen in full colour, but in very dark conditions it is seen in black and white (shades of grey).*

Explanation: bright light uses only the cones (very dim light uses only the rods). There are three types of cone, each sensitive to a different range of wavelengths (red, green, blue), so cones see in colour. There is only one type of rod, so rods see in black and white only.

Difference 2 *Detail: in bright light the image has high resolution (fine detail), but in very dark conditions the image has low resolution.*

Explanation: each cone has its own nerve fibre to the brain, so cones give high resolution. In dim light only rods are used, and several rods share one nerve fibre, so the brain cannot tell which rod was stimulated and the resolution is low.



According to some legends, in the 17th century a pirate with two healthy eyes covered one eye with a patch to keep the eye in the dark. The patch was removed when going from bright conditions outside to the very dark conditions below decks in an enemy ship.

It was necessary for the pirate to put the patch on about 45 minutes before going into the very dark conditions inside the ship.

0 1 . 2

What is the name of the process which occurs when the pirate's eye is covered by the patch?

Tick (✓) **one** box.

[1 mark]

aberration

☐

accommodation

☐

adaptation

☒

adjustment

☐

0 1 . 3

Discuss why it was necessary to wear the eye patch for 45 minutes before entering the ship.

[3 marks]

Under the patch the eye is in the dark, so its rods adapt to the dark

(dark adaptation) while the other eye is in bright light.

Adaptation takes time (about 30 to 45 minutes) because the rods have

to regenerate rhodopsin (visual purple), reversing the effect of bleaching

of the rods by bright light.

So when the patch is removed below decks, the eye is already

dark-adapted, and the pirate can see immediately in the very low light

levels.



0 2

A sound wave produces a maximum increase in pressure on an ear of $2.5 \times 10^{-3} \text{ N m}^{-2}$.

This causes a maximum increase in pressure in the fluid of the inner ear of $5.0 \times 10^{-2} \text{ N m}^{-2}$.

0 2 . 1

Explain how the ossicles contribute to this increase in pressure in the fluid of the inner ear.

[2 marks]

The ossicles act as levers (with a lever ratio of about 1.5), so the force on the oval window is larger than the force on the tympanic membrane.

So they increase the force, and this larger force acts on the much smaller area of the oval window, giving a larger pressure in the fluid.

0 2 . 2

The ear's tympanic membrane can be assumed to be a circle of diameter 1.0 cm.

Calculate the area, in m^2 , of the oval window.

[3 marks]

$$\text{Area of tympanic membrane} = \pi d^2/4 = \pi \times (0.010)^2/4 = 7.85 \times 10^{-5} \text{ m}^2$$

$$\text{Pressure ratio} = (5.0 \times 10^{-2})/(2.5 \times 10^{-3}) = 20$$

$$\text{Ossicles multiply the force by 1.5, so area ratio} = 20/1.5 = 13.3$$

$$(\text{Check: } F \text{ on drum} = 2.5 \times 10^{-3} \times 7.85 \times 10^{-5} = 1.96 \times 10^{-7} \text{ N;}$$

$$F \text{ on window} = 1.96 \times 10^{-7} \times 1.5 = 2.94 \times 10^{-7} \text{ N})$$

$$\text{Area of oval window} = 7.85 \times 10^{-5}/13.3$$

$$= (2.94 \times 10^{-7})/(5.0 \times 10^{-2}) = 5.9 \times 10^{-6} \text{ m}^2$$

$$\text{area} = \underline{5.9 \times 10^{-6}} \text{ m}^2$$

5



Turn over for the next question

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0 5

0 3

X-ray photons can be used to treat cancerous tumours in radiotherapy. Some photons are absorbed by healthy tissue before they reach the tumour.

Photons with a range of energies are generated in an X-ray machine.

Table 1 shows the linear attenuation coefficient of brain tissue for photons of energy 100 keV and 500 keV.

Table 1

Energy / keV	Linear attenuation coefficient of brain tissue / cm^{-1}
100	0.15
500	0.087

0 3 . 1

Deduce whether photons of energy 100 keV or 500 keV are better for treating a brain tumour at a depth of 11 cm.

[4 marks]

$$I = I_0 e^{-\mu x}, \text{ so fraction reaching tumour } I/I_0 = e^{-\mu x}$$

$$100 \text{ keV: } I/I_0 = e^{-0.15 \times 11} = e^{-1.65} = 0.19$$

$$500 \text{ keV: } I/I_0 = e^{-0.087 \times 11} = e^{-0.957} = 0.38$$

$$(\text{half-value thickness } x_{1/2} = \ln 2 / \mu: 100 \text{ keV } 4.6 \text{ cm, } 500 \text{ keV } 8.0 \text{ cm})$$

500 keV photons are better: 38% of the 500 keV radiation reaches the tumour compared with only 19% at 100 keV, so less of the 500 keV radiation is absorbed by the healthy brain tissue on the way.

So 500 keV photons cause less damage to the surrounding healthy tissue.



0 3 . 2

Metal filters are used in X-ray machines to limit the damage to healthy tissues. **Table 2** gives data for possible filter materials.

Table 2

Energy / keV	Linear attenuation coefficient / cm^{-1}	
	Aluminium	Copper
100	0.44	3.8
500	0.23	0.73

Discuss whether it would be better to use aluminium or copper to filter the X-rays in Question **03.1**.

No calculations are required.

[2 marks]

Copper is better. It is better at removing the 100 keV photons, which would mostly be absorbed by and damage healthy cells.

Copper's μ at 100 keV (3.8) is about 5 times its μ at 500 keV (0.73), but only about 2 times for aluminium, so copper removes a larger fraction of the 100 keV radiation than of the 500 keV.

0 3 . 3

State and explain **one** other method used to limit exposure of healthy cells during X-ray radiotherapy.

[2 marks]

Method *Use a rotating beam (or multiple beams) centred on the*

Explanation *tumour.*

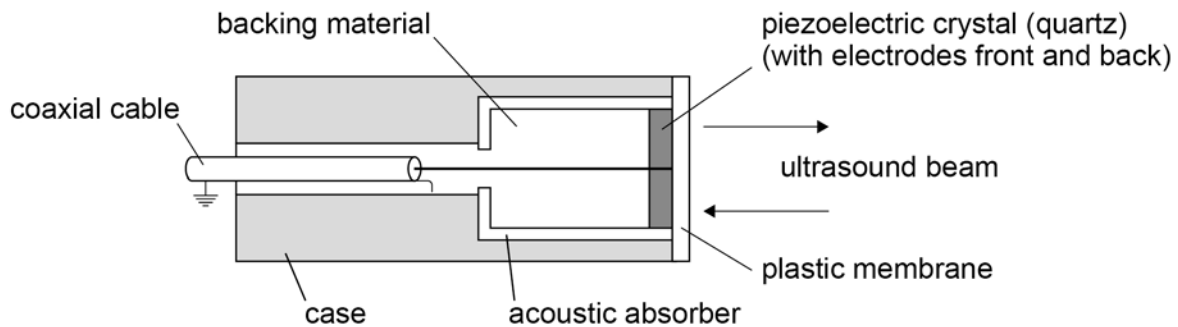
The X-rays enter through different paths and are spread out, so each part of the healthy tissue receives a lower dose, while the tumour receives the full dose all the time.

Turn over ►

0 4

Figure 1 shows an ultrasound transducer used to perform medical scans.

Figure 1



0 4 . 1

Explain how the transducer in **Figure 1** operates in medical diagnosis.

In your answer you should explain how

- an ultrasound pulse is produced by the transducer
- the reflected ultrasound pulse is detected by the transducer
- the transducer can both transmit a pulse and receive the reflected pulse.

[6 marks]

Producing a pulse: an alternating potential difference is applied across the piezoelectric crystal by the electrodes (through the coaxial cable).

This causes the crystal to expand and contract (vibrate), creating pressure waves in the crystal and plastic membrane, which pass into the body as ultrasound.

The frequency of the alternating pd is made equal to the resonant frequency of the crystal, so it vibrates with large amplitude, and this frequency is above 20 kHz (typically 1 to 15 MHz).

The pd is applied for only a very short time, so a short pulse of ultrasound is produced. The backing material then damps the crystal and stops it vibrating quickly, and the acoustic absorber absorbs ultrasound travelling backwards.

Detecting the reflection: the reflected ultrasound pulse is a pressure wave that reaches the crystal. This pressure wave causes the crystal to expand and contract, and this produces an alternating potential



difference across the crystal (the piezoelectric effect), which is sent along the cable to be processed.

Transmitting and receiving: the same transducer acts as a transmitter and a receiver because the piezoelectric effect works both ways. The crystal must have stopped vibrating (damped by the backing material) before the reflected pulse reaches it, so it is free to detect the echo.

The time between sending and receiving the pulse gives the depth of the boundary.

0 4 . 2

Ultrasound of frequency 1.0 MHz is used to scan a person's liver.

Estimate the resolution of the scan.

$$\text{speed of sound in liver tissue} = 1600 \text{ m s}^{-1}$$

[1 mark]

$$\lambda = c/f = 1600/(1.0 \times 10^6) = 1.6 \times 10^{-3} \text{ m}$$

$$\text{resolution} \approx \text{wavelength} = 1.6 \text{ mm}$$

$$\text{resolution} = \underline{1.6} \text{ mm}$$

Question 4 continues on the next page

Turn over ►



0 4 . 3

Ultrasound travels from a transducer through the chest wall to an air pocket inside the lung. From the air pocket, the ultrasound is then incident on lung tissue.

Calculate the percentage of the incident ultrasound intensity that is transmitted into the lung tissue.

$$\text{speed of sound in lung tissue} = 1580 \text{ m s}^{-1}$$

$$\text{density of lung tissue} = 1075 \text{ kg m}^{-3}$$

$$\text{speed of sound in air} = 330 \text{ m s}^{-1}$$

$$\text{density of air} = 1.3 \text{ kg m}^{-3}$$

[4 marks]

$$\text{acoustic impedance} = \text{density} \times \text{speed of sound (pc)}$$

$$\text{air: } 1.3 \times 330 = 429 \text{ kg m}^{-2} \text{ s}^{-1}$$

$$\text{lung tissue: } 1075 \times 1580 = 1.70 \times 10^6 \text{ kg m}^{-2} \text{ s}^{-1}$$

$$\text{fraction reflected} = ((\text{lung} - \text{air})/(\text{lung} + \text{air}))^2$$

$$= ((1.70 \times 10^6 - 429)/(1.70 \times 10^6 + 429))^2 = 0.999$$

So 99.9% is reflected

$$\text{transmitted} = 100 - 99.9 = 0.1\%$$

$$\text{percentage} = \underline{\quad 0.1 \quad} \%$$



0 4 . 4

Discuss whether an ultrasound scan would be suitable to investigate a tumour inside a lung.

[2 marks]

Not suitable: almost all (99.9%) of the ultrasound would be reflected because of the huge difference in acoustic impedance between air and tissue.

When going from the air inside the lungs to the lung tissue, only about 0.1% is transmitted, so almost no ultrasound reaches the tumour and no useful echo returns.

13**END OF QUESTIONS**

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